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Using Model Building in Structural Engineering to Enhance Understanding of Construction Principles and Methods

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Abstract

This paper presents a new model building exercise in a second year module in the Department of Civil & Structural Engineering in the Dublin Institute of Technology (DIT). The activity aimed to improve students' understanding of structural engineering, construction principles and methods. It allowed students to practically apply lecture material and construct a scaled model giving them an opportunity to study and visualise a real structure and generate their own ideas on how it should be assembled within a constructivist active learning environment. As a result, lectures were found to be more interactive and students more engaged in the discussions and provided a pathway to bridge the gap between theory (presented in lectures) and the reality of their professions, which can aid them in their graduate careers. It is hoped that this type of active learning can be used in other engineering programmes to improve student understanding and as an opportunity to better apply lecture material to the real world.

Keywords: model building, structural engineering, active learning, constructivist classroom

Introduction

Engineers need to be able to apply their education throughout their career. One of the best ways to allow students do this while in higher education is employing creative learning which uses practical ways to demonstrate theoretical principles (Ji & Bell, 2000; Lowman, 1995; Wankat & Oreovicz, 1993; Prince, 2004). The construction of scale models provides an enhanced learning experience for students, which in turn increases interest and motivation while developing a better understanding of how a structure ‘pieces together’ from the foundations to the rising walls to the first floor slabs which are supported on the cavity walls which support the roof etc. It is vital that this linking of the various elements is understood so when the student enters industry he/she understands the programming and scheduling of construction projects.

The use of such models to ‘see’ and interpret structural drawings is the most effective and instant way of completely understanding and communicating a concept (Ji & Bell, 2000). Architects regularly use scale models to improve both their and others’ understanding of the structure, particularly for complicated interfaces and spatial arrangements. Ji & Bell (2000) in their paper described ways that structural concepts could be made observable and touchable in class teaching. They highlighted how physical models can be used to illustrate structural concepts in conjunction with related engineering examples and appropriate research output. They concluded that using simple demonstrations in lectures, students are more receptive to the theoretical elements of the course. Overall, they found this type of approach helped students to grasp structural concepts and makes teaching and learning more interactive and interesting.

Atman *et al.* (2004) in their paper reported the results of an in-depth study of engineering approaches to open-ended design problems. From a large number of 4th and 1st year undergraduate engineering students working on two design problems, the results showed the 4th year students produced higher quality solutions, spent more time solving the problem, considered more alternative solutions and made more transitions between design steps than the 1st years. They also confirmed that the choice of task is very important.

Kruger & Cross (2006) presented data from protocol studies of nine experienced industrial designers, performing the same task to develop an expertise model of a product design process. This was used to identify four different cognitive strategies employed by the designers namely problem, solution, information and knowledge driven design strategies and then related to task outcomes such as solution quality and creativity. It was found that designers using a solution driven strategy tended to have lower overall solution quality but higher creativity scores. Designers using a problem driven design strategy produced the best results in terms of the balance of both overall solution quality and creativity.

The authors concluded that individual differences between designers were clear in most of the data relating to both design process and solution outcomes, even though they were performing the same task under the same conditions. The data suggested that most designers employ either a problem driven or a solution driven design strategy, with each being equally prevalent. Contrary to expectations, solution driven design did not feature clearly as the dominant strategy.

It is for these reasons that a new 'hands-on' model building activity was introduced into an existing second of a four year Civil/Structural Engineering Honours degree programme in the

Dublin Institute of Technology. The aim of the study was to improve students' understanding of construction principles and real engineering structures.

Active Learning within Structural Engineering

The benefits of proactive teaching in higher education generally are well documented. The well known Bloom's Taxonomy (Bloom, 1956) places creativity as the most influential of its learning activities. The relationship between lectures and application is important for learning outcomes and, if provided, can create the '*light-bulb effect*' in some students as lectures are contextualized into real-life problems. This constructive alignment (Biggs, 1999) between lectures and coursework/assessment can help students apply the material and better achieve the required learning outcomes.

Active learning in structural engineering is primarily focused on students engaging in problem-solving activities to apply lecture material. Prince (2004) presented results of a study examining the effectiveness of active learning in an engineering faculty and challenging traditional assumptions about engineering education. Although problem-based learning activities are unlikely to see significant improvements in student marks, it is more likely to positively influence student attitudes, study habits and, perhaps most importantly, an improvement in student engagement and retention of lecture material.

However, simply introducing an activity into the classroom (like a question and answer session for example) is not a good application of active learning as the type of activity influences how much of the material is retained (Di Vesta & Smith, 1979). Therefore, activities must be designed around the learning outcomes and promote thoughtful

engagement which is a widely accepted concept with considerable evidence to support its effectiveness of student engagement on a broad range of learning outcomes.

Including active learning in a group environment, using collaborative learning, has been shown to give better results than individuals working alone. In a review of 90 years of research, Johnson *et al.* (1998, 1998a) found that cooperation improved learning outcomes relative to individual work. An additional benefit to this type of approach is that collaboration reduces attrition in technical programs by 22%, a significant finding when technical programs are struggling to attract and retain students in modern engineering programmes. Their evidence suggests that collaboration is particularly effective at improving retention of traditionally underrepresented groups (Fredericksen, 1998; Berry 1991). In conjunction with this, research has shown a broad support for cooperative learning as it is more effective in promoting a range of positive learning outcomes including enhanced academic achievement while providing an environment to enhance students' interpersonal skills (Prince, 2004).

It has been argued (Norman & Schmidt, 2000, p.45) that “*problem-based learning does provide a more challenging, motivating and enjoyable approach to education.*” While problem-based learning has been used in undergraduate engineering programmes, there is very little data available for its effectiveness despite the evidence that it improves the long-term retention of knowledge compared to traditional instruction (Gallagher, 1997). It also promotes better study habits among students including increased library activity and class attendance.

However, for the activity to be successful, the lecturer must have both a deep and broad foundation of factual knowledge in their fields (Prince, 2004). The use of real-problems to

solve in small groups using cooperative learning structures appear to be the best form of activity to increase productivity and enjoyment as the students can better relate to the task. Nevertheless, traditional engineering courses do not use the technique as frequently as they should as it can be difficult to analyse because of the unclear link with student learning outcomes.

Development of Structural Model Building

Welsh & Klosky (2007) have developed an online tool (www.handsonmechanics.com) to help include physical models in the classroom, which has been shown to enhance student learning. Each physical model presented has a description, the theoretical background, pictures and/or video of the set-up and demonstration. The web site itself is a result of the authors' belief that physical models rather than just computer simulations should be included as an integral part of every engineering student's education. Physical models describing statics, dynamics, mechanics of materials, material science, thermodynamics, fluid dynamics, heat transfer, and structural analysis were made in conjunction with the Department of Civil and Mechanical Engineering, United States Military Academy (USMA), in West Point. The website contains a list of each topic and available models as well as demonstrations. The developers are open for submission of new materials from interested parties outside of the USMA.

The vision of the developers is to provide a one-stop location for educators interested in using physical models to enhance the quality of the learning in their classrooms. Feedback from students and external users of the site is that the inclusion of physical models will enhance student learning especially for more difficult topics. The authors believe that while many

engineering faculties recognize the need to include physical models, the lecturer lack the basic knowledge, time and resources necessary to implement classroom demonstrations. However, this website provides a useful tool to present proven physical models and demonstrations that can be quickly implemented. Wankat & Oreovicz (1993) and Lowman (1995) both emphasise that by using physical models helps develop a student-centred classroom while simultaneously improving the presentation and performance of the lecturer with the end-produce being an energized, active classroom and a better educated student.

Wankat & Oreovicz (1993) state that more scholarly, problem-based and other learning activities and approaches have become more common in the past two decades as a consequence of engineering program accreditations which require continual improvements of how learning outcomes are assessed. They conclude that the main challenge to modern engineering education is linking the scholarship of teaching and learning equal to discovery. However, the main barrier to this is how marks are fairly awarded and a lack of pedagogical knowledge in academic staff.

Lowman (1995) describes third level teaching college teaching as a ‘dramatic and human arena’ with the lecturer acting as a ‘skilled artist’. His approach to teaching and learning effectiveness can be described in the simple equation:

$$Q(I) = (IE + PR)$$

where QI is the quality of instruction which is achieved by combining Intellectual Excitement (IE) and a Positive Rapport (PR) in students. The model building activity at the heart of this current study is an example of the ‘Constructivist Classroom’, where students, in this context, learn about structural engineering and building technology through making models and

reflecting on them through the semester. With regular lecturer feedback, they are encouraged to trigger alternatives and develop improved designs which are again reflected on when they are next submitted, thereby ‘constructing their knowledge’. This approach develops active learners rather than passive listeners, giving them ownership of their ideas.

Felder (1988) described how students learn in many ways, some of which include physical and mathematical model building. The extent of what the student actually learns is governed both by their ability and prior preparation and by the compatibility of his or her learning style by the instructor’s teaching style. If a mismatch between these last two exists, students can become bored and uninterested in class. Felder (1988) states that most engineering students are visual, sensing, inductive and active learners. However, most engineering education is auditory, abstract (intuitive), deductive, passive and sequential. Therefore, giving students an active task to apply their learning is particularly well suited to engineering. The inclusion of a small number of teaching methods to align with these styles will be able to satisfy the needs of most or all of the students in any class.

Methodology

It was against this background that the idea of introducing an active learning activity into the module was explored. To assess its applicability and establish if the students would ‘buy into it’, a short survey was undertaken of previous year students (Third and Fourth year Level 8 Civil & Structural Engineering) who had already taken the module in their second year. The survey asked the students if they believed this exercise would have improved their understanding of the lecture material. When these students undertook the module, the coursework element consisted of regular typed reports based on different aspects of building technology, namely site investigations, ground floor construction, cavity walls, roofs, etc.

McKeachie *et al.* (1987) reports that the incorporation of active learning strategies into the daily routine of classroom instruction should be undertaken and offer a questionnaire to help decide if students would 'sign-up' to the approach and if they feel the activity would be of benefit to them and increase their interest levels. They advise that extent to which these active learning strategies are incorporated into the lecture depends on the course objectives and the instructor's teaching style. One example given to construct the survey is how the activity will achieve the course objectives and associated learning outcomes. Questions to be included in any survey should include:

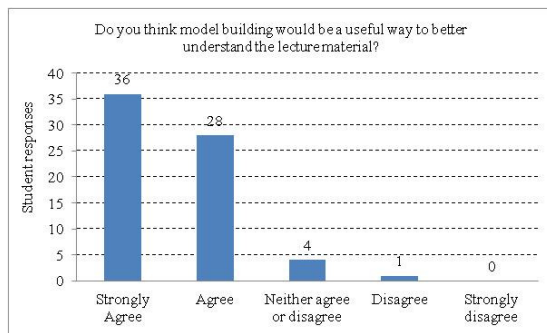
- what should students know (knowledge)
- what should students be able to do (skills)
- what should students feel (attitudes)

The students were given the survey shown in Table 1 below following a presentation of the proposed changes. A total of 69 students were questioned and the results can be found in Figures 1 (a-c) below. Students reported that they considered that the proposed activity would have been a better approach to enhance their understanding of the lecture material, that their attention levels would have been increased and have stimulated their interest levels in the subject. The results confirmed that the proposed coursework activity should be introduced into the module as an appropriate way to improve understanding of the material, re-energise the classroom and introduce an active learning activity into this module.

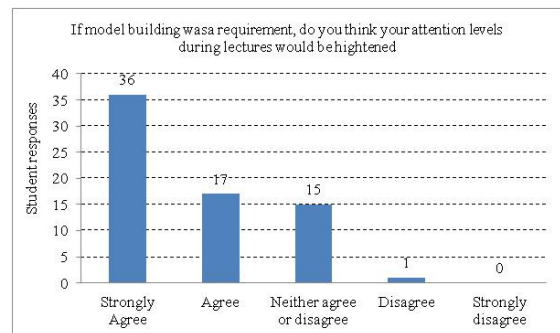
Table 1: Student Survey to assess student attitude to new model building activity in DT024-2

Building Technology

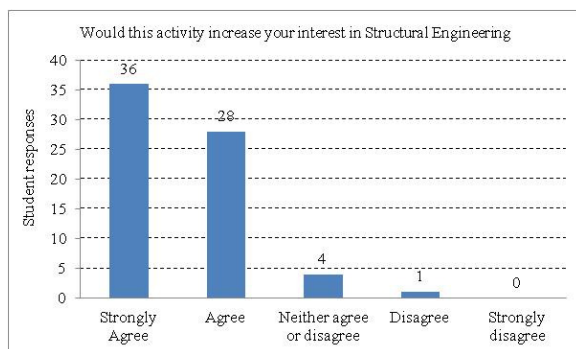
	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
Do you think model building would be a useful way to better understand the lecture material?					
If model building was a requirement, do you think your attention levels would be heightened?					
Would this activity increase your interest in Structural Engineering?					



(a)



(b)



(c)

Figure 1 Student responses to survey

The introduction of this new approach will achieve the aims of the module (equip the student with good construction practice and detailing) and the learning outcomes, namely:

- applying current regulations and design codes where applicable;
- demonstrating an understanding of the material used in the industry;
- understanding the main construction principles and techniques used in the construction industry.

Implementation of the Model Building Activity

The activity was implemented in a group work structure. For this, the class size of 16 was divided into four groups, each containing four students. Each group was then assigned a structure with drawings, technical and structural information in order for them to start constructing a scale model. An example of one of the structures is shown in Figure 2 below which is a two-storey community centre. The structures were selected from a sample the authors had designed in their professions before entering academia. Each structure had a different foundation type and roof arrangement and included:

- a portal frame building with pad foundations and a metal insulated roof (Group 1);
- a school building with traditional strip foundations and prefabricated roof (Group 2);
- an animal care unit with ground beams, piles and prefabricated roof (Group 3);
- a community centre with a deep piled raft foundation and cut timber roof (Group 4).

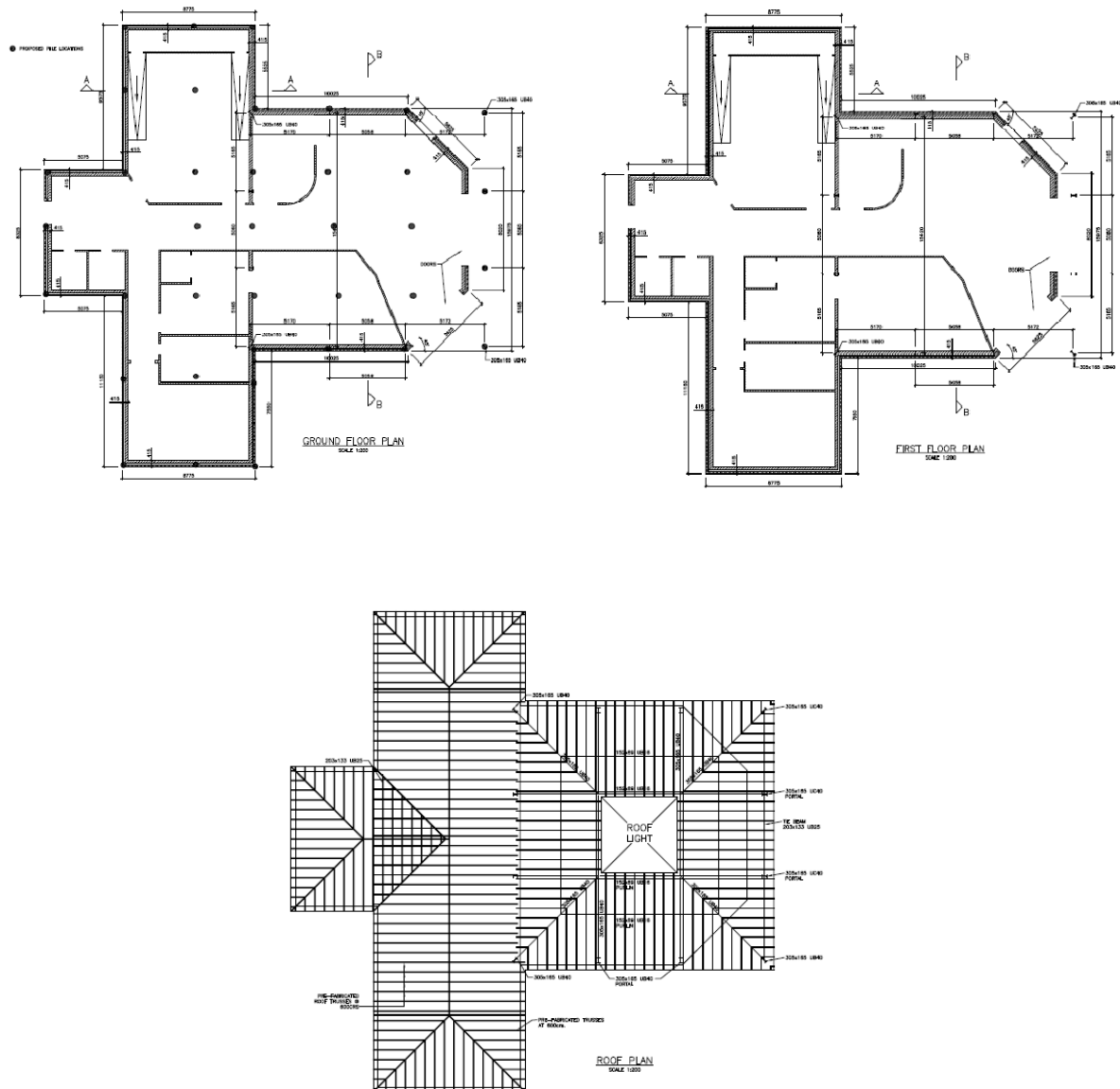


Figure 2 Drawings of two-storey community centre given to Group 4

The focus of the activity was not for the students to design the various elements, but instead to better understand how they are assembled on site and be able to highlight different structural details. Therefore, each group were also provided with a full set of marked-up structural arrangement drawings including the steel beams sizes, concrete slabs etc. A site investigation report was also prepared by the lecture and given to the students which explained why the particular foundation type was being employed.

To ensure students worked on their model throughout the semester, they were required to present it in four stages; namely the foundation model including the ground floor and rising walls, the first floor and the roof. The final submission included the entire model with the three sections connected. Ultimately, each model had to provide a cross-section near the gable end showing all levels from foundation to roof so the various structural details could be clearly seen.

Results and Discussion

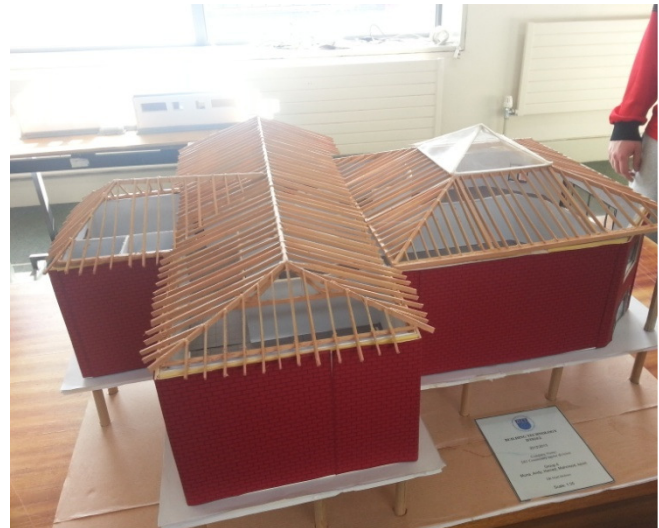
Throughout the Semester, students were actively engaged in the process and presented their models with enthusiasm. An example of the submissions for the community centre is shown in Figure 3 below.

As may be seen, the models were of a high standard especially considering they were the first students doing this activity, and were given little to base their work. The models demonstrate that the students did understand what was required, and built them in a scaffolded way with each element following on from the previous. For instance, the rising walls are only built when the foundations are constructed and the first floors are supported on the cavity walls etc.

This demonstrates a reasoned approach to construction activities which was discussed during lectures. In a learning context, this reasoned progression could be termed ‘induction’ learning (Felder, 1988). However, Felder (1988) argues that most engineering curricula follow a ‘deduction’ learning approach where the governing principles are stated which are then worked on using an efficient manner where the material is already understood to some level.



(a)



(b)



(c)



(d)

Figure 3 (a) Foundation, (b) First Floor and (c-d) Roof models for Group 4

Notwithstanding the belief that engineering courses use a ‘deduction’ approach, Felder (1988) suggests that most engineering students view themselves as inductive learners. Furthermore, it was also discovered that lectures identify their own learning styles as a combination of both inductive and deductive learners but all agreed that their teaching was almost purely deductive. Therefore, Felder (1988) believes that a mismatch exists between

the learning styles of most engineering students and the teaching style to which they are almost invariably exposed.

Most formal education involves a logically ordered presentation of material which represents a sequential learning technique. This approach is best suited to this type of activity where the structure is constructed in a logical sequenced way. However, while this approach is best suited to some students, not all are comfortable with it. Global learners use the 'light-bulb' effect where the material suddenly makes sense to them at which point they can understand the material well enough to apply it. This, as discussed earlier, was observed in the exercise where lecture notes and details clicked for some students and could be easily incorporated into their models.

Sequential learners follow a reasoned approach and make steady progress through the semester. However, for global learners, who often make intuitive leaps, education can be a difficult experience as they are unable to follow the curve set by their colleagues. Felder (1988) suggests that global learners are the last students who should be lost to higher education as they are the synthesizers, the multidisciplinary researchers, the systems thinkers and can be truly outstanding engineers provided they survive the educational process.

It is clear, therefore, that both sets of learners, sequential and global, were able to participate in this activity as students were given the freedom to devise their own methods of constructing the structure rather than being forced to adopt the authors' strategy. Felder (1988) suggests that one valuable way for instructors to serve both types is to assign problems that involve generating alternative solutions and bringing in material from other areas, which was employed here throughout. While constructive feedback was provided after

each submission, students were encouraged to openly and confidently suggest alternatives, which, at this stage in their education, is very encouraging. While details were provided on particular aspects of the structure, no guidance was given as to how this should be shown or which materials would suit best.

Overall, the students did create viable models for their structures which, considering the number of different materials they contained (steel, concrete, masonry and timber) was a satisfactory outcome. It demonstrated that they understood the drawings and how the building was assembled using their lecture notes as appropriate. If they could not understand the drawing or a particular element within it, they did not hesitate in coming forward and asking for guidance.

Lemons (2010) reported on the emerging movement to integrate model-building in engineering programs. A framework currently being pioneered in MIT with 23 other Universities have adapted the Conceive-Design-Implement-Operate (CDIO) agenda which will emphasise an integrated hands-on, product-building skills initiative in the early stages of degree programmes. This will also be sustained throughout the curriculum (Ho & Ryan, 2009) with the overarching aim to provide an active learning experience to enhance students' design abilities and provide deeper concept learning.

Lemons (2010) concluded that design-and-build exercises enhances students' design abilities, provides deeper learning of concepts and lays the foundation for developing more theoretical knowledge structures.

Evaluation of the Activity Driven Approach

As discussed earlier, it was decided at the end of the process that students involved in the activity would be asked to complete a survey asking for their thoughts on what they just completed. Using the suggestions offered by McKeachie *et al.* (1987), the questionnaire sought to determine if the students had ‘sign-up’ to the activity and if they felt it was of benefit to them while increasing their interest levels in lectures. This is important aspect to know as the activity could only continue if the course objectives learning outcomes were achieved.

Therefore, students were asked to complete the survey shown in Table 2 which assesses if the objectives set out by McKeachie *et al.* (1987) were achieved. As may be seen from the responses in Figures 4 (a-b) the students agreed that the activity was helpful in understanding the material and it did improve their attention levels during lectures.

Table 2: Student survey to assess if the objectives of the exercise were met following completion.

	Strongly agree	Agree	Neither agree or disagree	Disagree	Strongly disagree
Do you think model building has been a useful way to better understand the lecture material?					
Do you think your attention levels have been heightened in lectures as a result of this activity?					

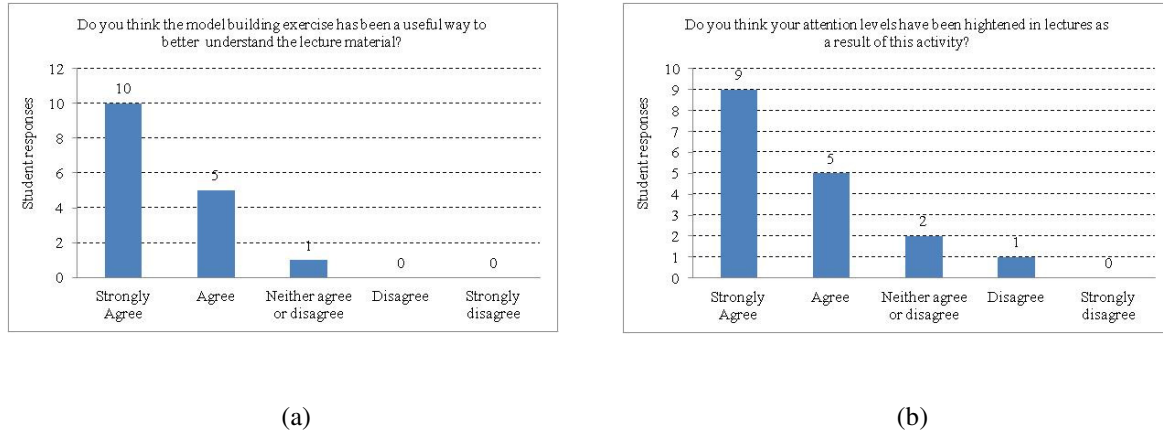


Figure 4 Student responses to survey after the activity was complete

Conclusion

The main finding from this active learning approach is that model building allows students to better visualise, evaluate and understand structural engineering and construction technology.

The activity has helped students differentiate between theoretical (introduced through lectures) and real structures. It has given them the confidence to apply lectures, and offer alternatives to the techniques and materials specified.

This concurs with previous findings (Ji & Bell, 2000; Lowman, 1995; Lemons *et al.*, 2010; Welch & Klosky, 2007; Felder, 1988) that model building is an underutilized pedagogical learning tool which, as has been shown here, can enhance engineering education. It is proposed that the activity be introduced into other modules on the programme in the next academic year to improve student understanding and interest in other relevant topics in engineering.

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